Detailed North-South Cross Section Showing Environments of Deposition, Organic Richness, and Thermal Maturities of Lower Tertiary Rocks in the Uinta Basin, Utah

Pamphlet to accompany
Scientific Investigations Map 3304

U.S. Department of the Interior
U.S. Geological Survey

COVER. Evacuation Creek, Uinta Basin, northeastern Utah. Photograph by R.C. Johnson, USGS, 1981.

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SALLY JEWELL, Secretary

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Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Volume	
gallon (gal)	3.785	liter (L)
	Mass	
ton, short (2,000 lb)	0.9072	megagram (Mg)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
megagram (Mg)	1.102	ton, short (2,000 lb)

Altitude, as used in this report, refers to distance above the vertical datum.

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Detailed North-South Cross Section Showing Environments of Deposition, Organic Richness, and Thermal Maturities of Lower Tertiary Rocks in the Uinta Basin, Utah

By Ronald C. Johnson

Introduction

The Uinta Basin of northeast Utah (fig. 1) has produced large amounts of hydrocarbons from lower Tertiary strata since the 1960s (Lucas and Drexler, 1976). Recent advances in drilling technologies, in particular the development of efficient methods to drill and hydraulically fracture horizontal wells, has spurred renewed interest in producing hydrocarbons from unconventional low-permeability dolomite and shale reservoirs in the lacustrine, Eocene Green River Formation. The Eocene Green River Formation was deposited in Lake Uinta, a long-lived saline lake that occupied the Uinta Basin, the Piceance Basin to the east, and the intervening Douglas Creek arch (figs. 1–3). The focus of recent drilling activity has been the informal Uteland Butte member of the Green River Formation (Osmond, 1992) and to a much lesser extent the overlying R-0 oil shale zone of the Green River Formation (figs. 2, 4). Initial production rates ranging from 500 to 1,500 barrels of oil equivalent per day have been reported from the Uteland Butte member from horizontal well intervals that are as long as 4,000 feet (ft; Durham, 2013). The cross section presented here extends northward from outcrop on the southern margin of the basin into the basin's deep trough, located just south of the Uinta Mountains, and transects the area where this unconventional oil play is developing. A major fluvial-deltaic system entered Lake Uinta from the south (Cashion, 1967), and this new line of section is ideal for studying the effect of the sediments delivered by this drainage on hydrocarbon reservoirs in the Green River Formation. The Monument Butte Oil Field, which is one of the fields located along this line of section, has produced hydrocarbons from conventional sandstone reservoirs in the lower part of the Green River Formation and underlying Wasatch Formation since 1981 (Lomax, 1993). The cross section also transects the Greater Altamont-Bluebell field in the deepest part of the basin, where hydrocarbons have been produced from fractured, highly overpressured marginal lacustrine and fluvial reservoirs in the Green River, Wasatch, and North Horn Formations since 1970 (Smouse, 1993). Datum for the cross section is sea level so that hydrocarbon source rocks and reservoir rocks could be integrated into the structural framework of the basin.

Lithologies shown at each drill hole are modified from American Stratigraphic Company sample descriptions and available mudlogs. Lithologies shown for surface sections on the south end of the cross section are modified from Cashion (1967). Oil yields, in gallons per ton (GPT), that were measured using the Fischer assay method are available for 7 of the19 drill holes. These samples were analyzed in the 1970s to evaluate the oil shale resources in the Uinta Basin, and were used in the recent assessment of the in-place oil shale resources in the basin (Johnson and others, 2010b). Other information on the cross section includes: (1) results from drill-stem tests and perforations, (2) mudweights used during drilling, and (3) and Rock-Eval and vitrinite reflectance (R_o) analyses from Anders and others (1992). The goal of this study is to determine if the oil found in the Uteland Butte member and R-0 zone was derived locally from mature source rocks or migrated into the dolomite and shale reservoirs from deeper, more mature source rocks.

Stratigraphic Subdivisions of the Green River Formation

The Green River Formation of the Uinta and Piceance Basins was deposited in Eocene Lake Uinta, a large saline lake that formed when two much smaller freshwater lakes, located in each of the Piceance and Uinta Basins expanded during the Long Point transgression (Johnson, 1985) and merged into one lake. Lake Uinta increased in salinity through time, ultimately precipitating large quantities of nahcolite ($NaHCO_3$) and halite (NaCl). The Uteland Butte member of the Green River Formation was deposited in the earlier freshwater lake, whereas the R-0 zone was the first oil shale zone deposited in the newly, expanded and increasingly saline Lake Uinta (figs. 2, 4).

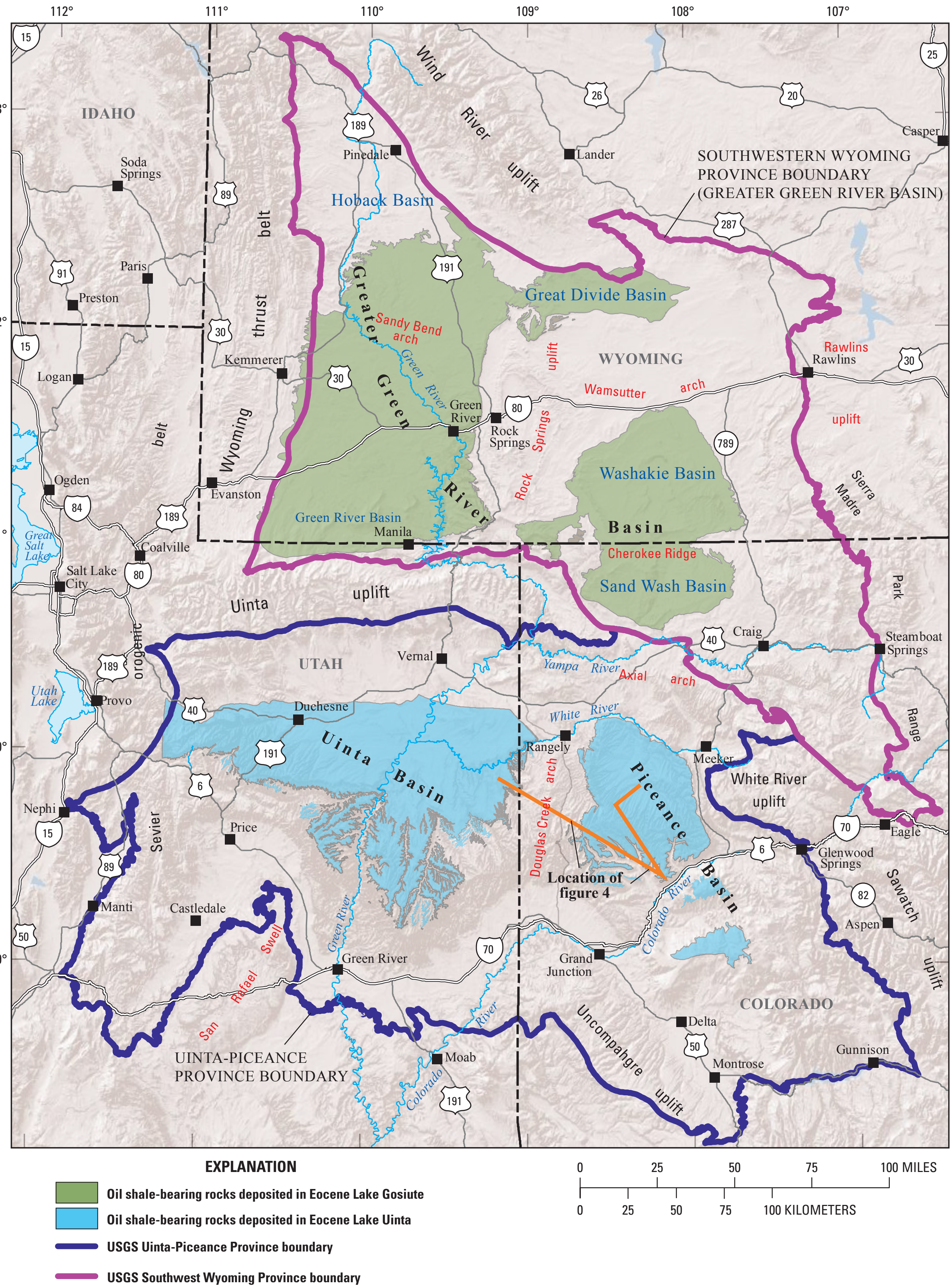
112°
111°
110°
109°
108°
107°
43°
42°
41°
40°
39°
IDAHO
WYOMING
UTAH
COLORADO
SOUTHWESTERN WYOMING PROVINCE BOUNDARY (GREATER GREEN RIVER BASIN)
UINTA-PICEANCE PROVINCE BOUNDARY
Wind River uplift
Hoback Basin
Greater Green River Basin
Great Divide Basin
Washakie Basin
Sand Wash Basin
Green River Basin
Sandy Bend arch
Wamsutter arch
Rock Springs uplift
Cherokee Ridge
Rawlins uplift
Sierra Madre
Park Range
Wyoming thrust belt
Sevier orogenic belt
Uinta uplift
Axial arch
Uinta Basin
Piceance Basin
Douglas Creek arch
White River uplift
Sawatch uplift
Uncompahgre uplift
San Rafael Swell
Location of figure 4
Great Salt Lake
Utah Lake
Green River
Yampa River
White River
Colorado River
Pinedale
Lander
Casper
Soda Springs
Paris
Preston
Logan
Kemmerer
Green River
Rock Springs
Rawlins
Ogden
Evanston
Coalville
Salt Lake City
Manila
Vernal
Craig
Steamboat Springs
Provo
Duchesne
Rangely
Meeker
Nephi
Price
Manti
Castledale
Glenwood Springs
Eagle
Aspen
Green River
Grand Junction
Delta
Montrose
Gunnison
Moab
15
25
26
20
189
89
287
191
91
30
80
789
84
40
6
70
82
50
EXPLANATION
Oil shale-bearing rocks deposited in Eocene Lake Gosiute
Oil shale-bearing rocks deposited in Eocene Lake Uinta
USGS Uinta-Piceance Province boundary
USGS Southwest Wyoming Province boundary
0 25 50 75 100 MILES
0 25 50 75 100 KILOMETERS

Figure 1 (Previous page). Map showing extent of Uinta, Piceance, and Greater Green River Basins, and the approximate extent of oil shale in the Green River Formation. Sub-basins in the Greater Green River Basin are labeled in blue. Major uplifts are labeled in black, and minor structural arches are labeled in red. Extent of the Uinta and Piceance Basins (dark blue) is the same as the Uinta-Piceance Province boundary (U.S. Geological Survey Uinta-Piceance Assessment Team, 2003). Extent of the Greater Green River Basin (magenta) is the same as the Southwest Wyoming Province boundary (U.S. Geological Survey Southwestern Wyoming Province Assessment Team, 2005). For the extent of oil shale in the Piceance Basin, the base of the Parachute Creek Member of the Green River Formation as mapped by Tweto (1979) was used for all but the northwest part of the basin where the base of the lower member of the Green River Formation is used. For the extent of oil shale in the eastern part of the Uinta Basin, the base of the Parachute Creek Member, as mapped by Cashion (1973) and Rowley and others (1985), was used. In the western part of the Uinta Basin, the top of the informal Mahogany bed of the Green River Formation, as mapped by Witkind (1995), was used. In the northern part of the Uinta Basin, only the area where oil shale is at a depth of 6,000 ft or less is shown; this area was outlined by using a structure contour map of the top of the Mahogany oil shale bed compiled by Johnson and Roberts (2003). For the Sand Wash, Washakie, Great Divide Basins, and southeastern part of the Green River Basin, the base of the Tipton Shale Member of the Green River Formation as mapped by Tweto (1979) and Love and Christiansen (1985) was used to show extent of oil shale. For the western part of the Green River Basin, the base of the Wilkins Peak Member of the Green River Formation, and for the northern part of the Green River Basin, the base of the Laney Shale Member of the Green River Formation as mapped by Love and Christiansen (1985) were used.

Lake Uinta remained a single lake across both basins and the intervening Douglas Creek arch throughout most of its history, and as a result most stratigraphic units can be recognized in both basins (figs. 2, 4). Formal member subdivisions of the Green River Formation recognized in the Piceance Basin and eastern part of the Uinta Basin are the Garden Gulch, Parachute Creek, and Douglas Creek Members (figs. 2, 4). These units are difficult to trace in the western part of Uinta Basin where informal names are generally applied to subdivisions of the Green River Formation. Several informal nomenclature schemes have been used to subdivide the Green River Formation in the western part of the Uinta Basin including: (1) basal member, delta facies, and shaly facies (Bradley, 1931); (2) delta facies, and barren and saline facies (Ryder and others, 1976); and (3) lower, middle, and upper members of the Green River Formation (Weiss and others, 1990). Saline Lake Uinta persisted much longer in the central and western parts of the Uinta Basin than elsewhere in the Uinta and Piceance Basins. The informal terms "saline facies of the Parachute Creek Member" (Ryder and others, 1976) and "upper saline facies of the Parachute Creek Member" (Dyni, 1996; Brownfield and others, 2010) are commonly applied to these younger lacustrine deposits, which contain a different saline mineral assemblage than the underlying Parachute Creek Member including eitelite ($Na_2Mg(CO_3)_2$), shortite ($Na_2Ca_2(CO_3)_3$), and wegscheiderite ($Na_5(CO_3)(HCO_3)_3$ (Bradley, 1931; Erickson, 1952; Milton and others, 1954; Dane, 1955; Milton, 1957; Dyni and others, 1985; Dyni, 1996).

The name Garden Gulch Member is generally applied in the eastern part of the Uinta Basin and throughout the Piceance Basin to the clay-rich (mainly illite) oil shale interval that was deposited in offshore areas early in the history of Lake Uinta (Bradley, 1931). The R-0 zone consists of the lowermost part of this illitic oil shale interval and the L-1 zone contains the uppermost part (fig. 4). The name Parachute Creek Member is applied in the eastern part of the Uinta Basin and the Piceance Basin to the dolomitic oil shale that overlies the Garden Gulch Member (Bradley, 1931). As with the term Garden Gulch Member, the term Parachute Creek Member is not generally used in the western part of the Uinta Basin. The name Douglas Creek Member is applied to marginal lacustrine rocks in both the eastern part of the Uinta Basin and the western part of the Piceance Basin. In the western part of the Uinta Basin, the informal term "black shale facies" is applied to the combined R-0 part of the Garden Gulch Member and the offshore oil shale interval of the underlying freshwater lake phase, known as the Uteland Butte member (fig. 2; Picard, 1959; Ryder and others, 1976). The name Uinta Formation is applied to a sequence of sandstones and siltstones containing abundant volcanic debris that interfinger with the upper part of the Green River Formation (fig. 2; Cashion and Donnell, 1974). The name Duchesne River Formation has been applied to the fluvial interval consisting of buff and gray sandstone, red and pink shale, and conglomerate that overlies the Uinta and Green River Formations along the axis of the Uinta Basin (Walton, 1944; Cashion and Brown, 1956).

Cashion and Donnell (1972) recognized that the entire oil shale interval in the Piceance Basin and eastern part of the Uinta Basin could be subdivided into a series of oil-rich zones (R-1 through R-6) and oil-lean zones (L-1 through L-5; fig. 4). Subsequently, the names R-0 and L-0 zones were applied to the lowest oil shale units in the Green River Formation as shown in fig. 4 (for example, see Johnson and others, 1988). The R-0 through L-1 zones are generally equivalent to the Garden Gulch Member, and the remaining overlying oil shale zones compose the Parachute Creek Member. Oil shale units above the R-6 zone include—(in ascending order) B-groove, Mahogany zone, A-groove, bed 44 interval, and bed 76 interval. Although the oil shale interval above A-groove was not named by Cashion and Donnell (1972), they did trace several oil shale marker beds through that interval. Later, Donnell (2008) correlated 44 individual oil shale beds (not shown on fig. 4) above A-groove across much of the Piceance Basin and the eastern part of the Uinta Basin (fig. 4). All of

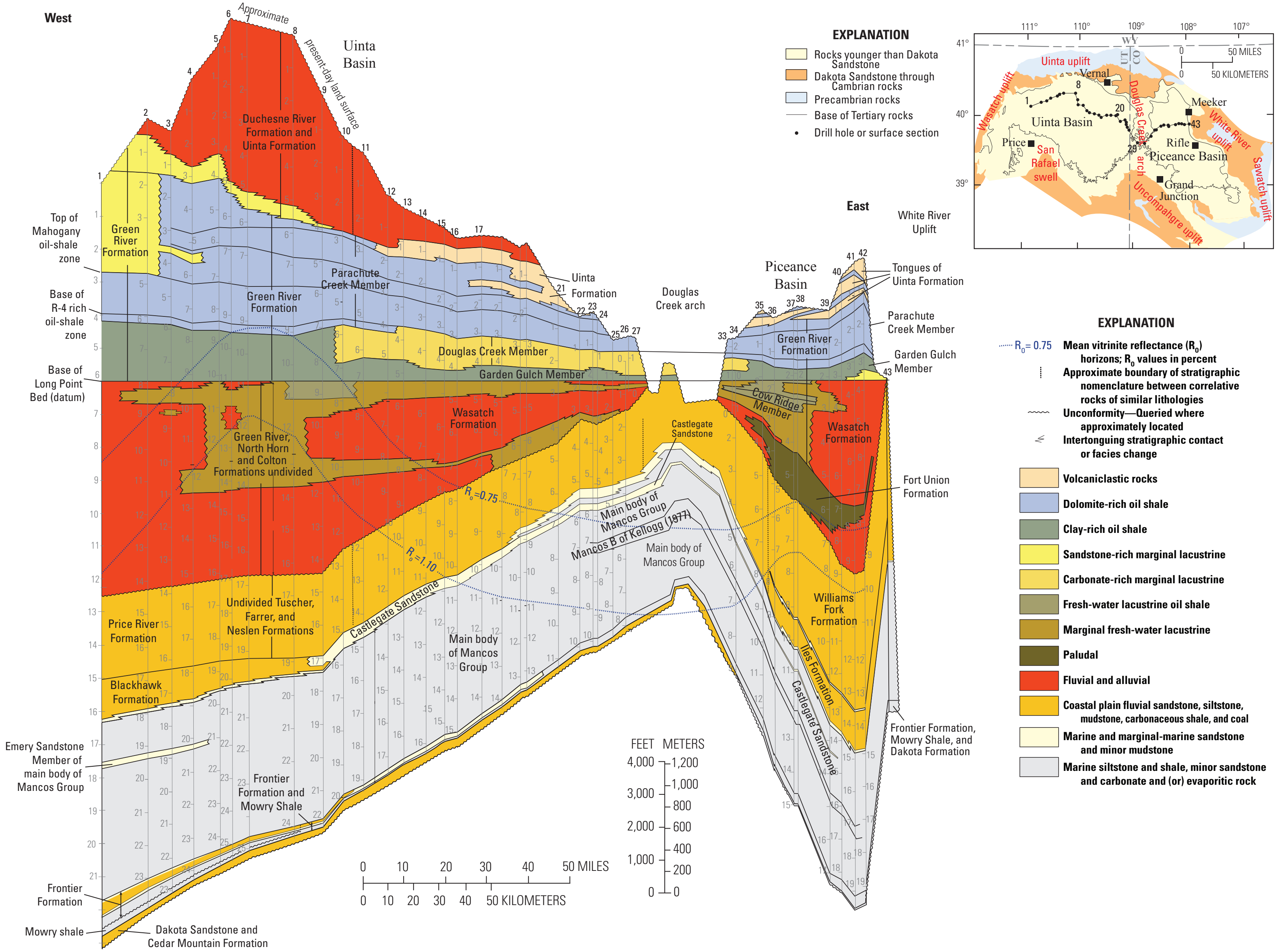

Figure 2. West-east cross section across the Uinta Basin, the Douglas Creek arch, and the Piceance Basin showing stratigraphic subdivisions, lithologies and variations in thermal maturity measured using vitrinite reflectance. Modified from Johnson and Roberts (2003).

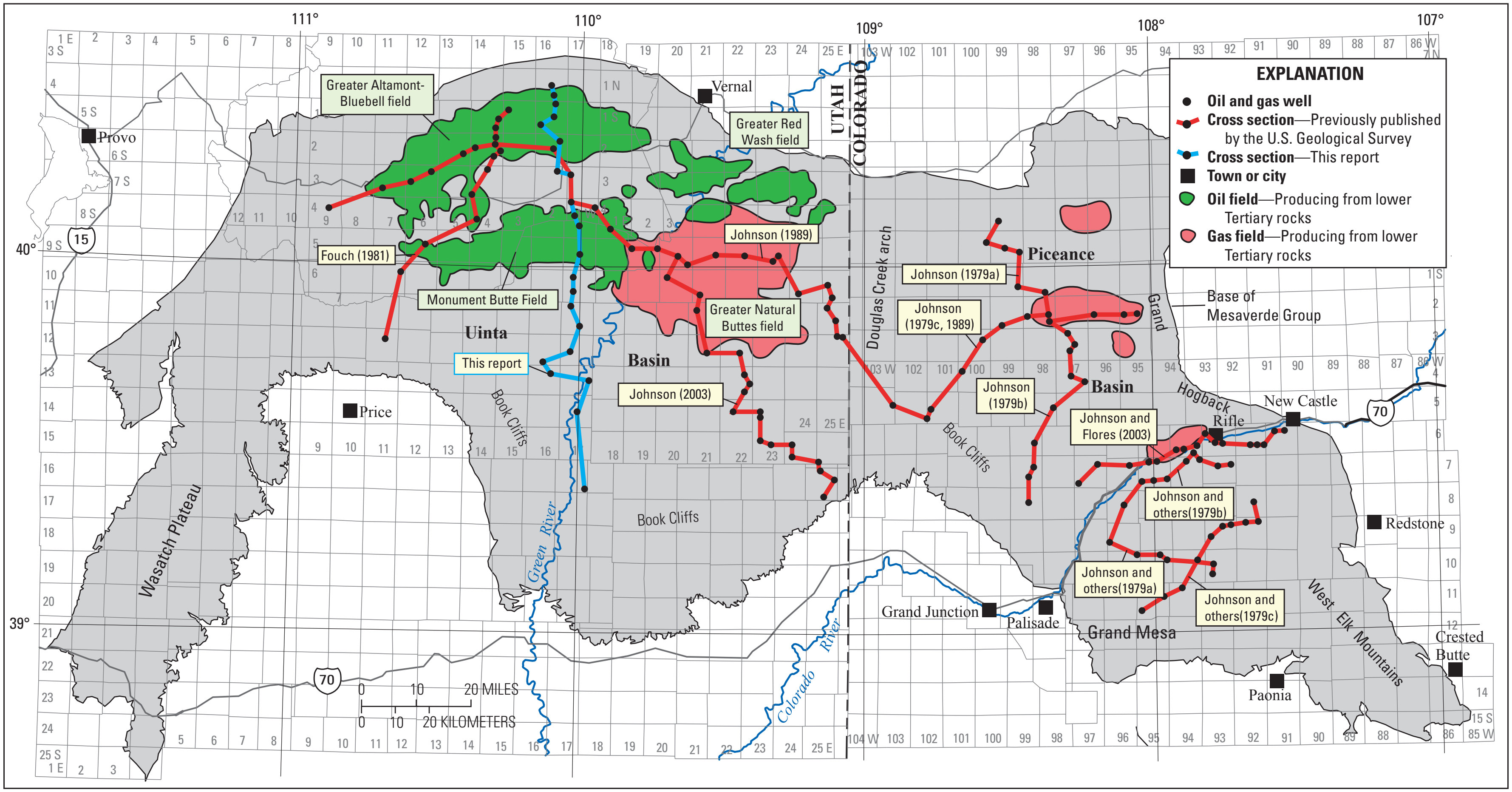

Figure 3. Index map showing detailed cross sections of upper Cretaceous and lower Tertiary rocks published by the U.S. Geological Survey in the Uinta and Piceance Basins (in red). North to south cross section of the Uinta Basin presented in this publication are shown in blue.

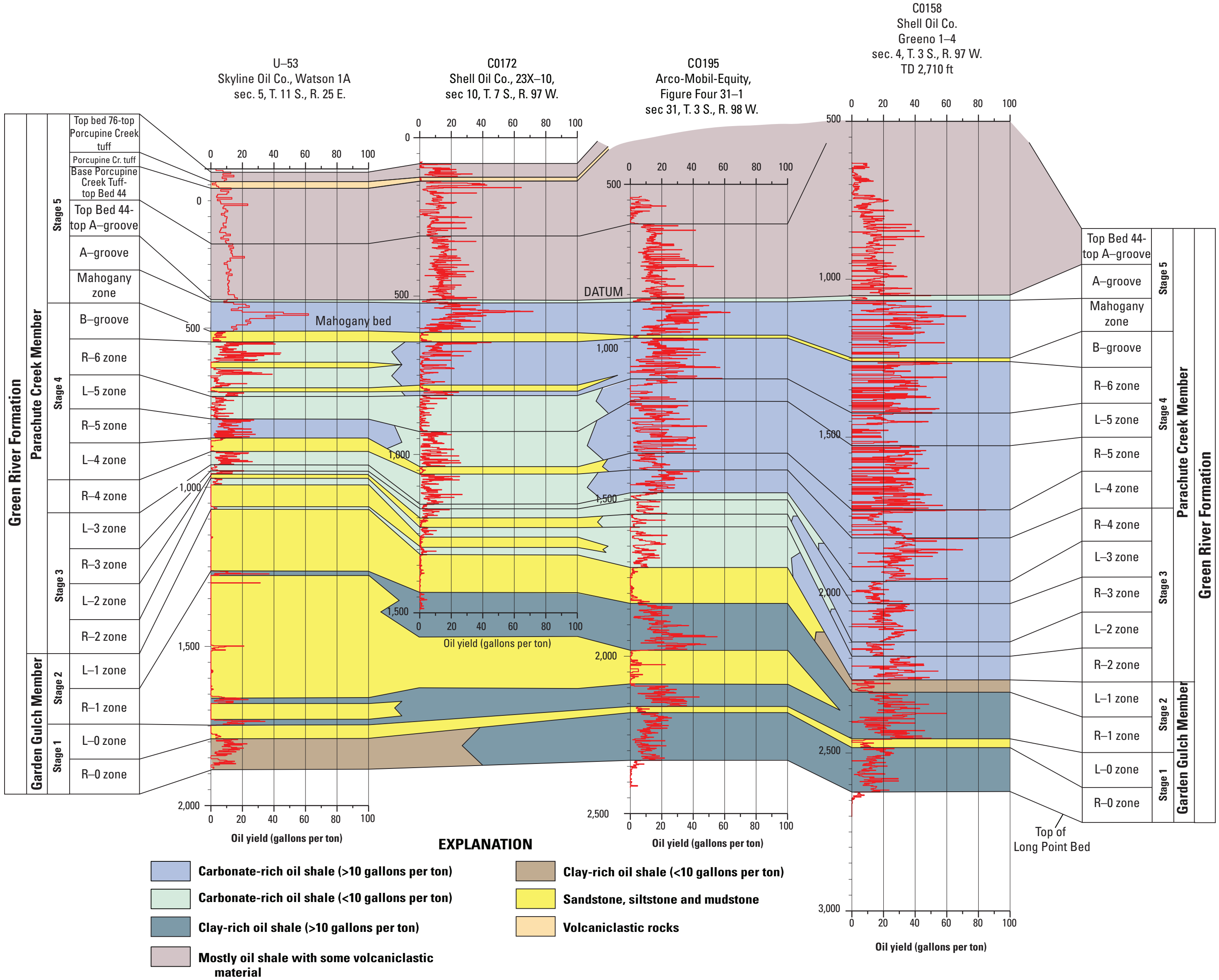

Figure 4. Cross section showing oil-yield histograms, members of the Eocene Green River Formation, correlation of rich- and lean-oil shale zones of Cashion and Donnell (1972), and stages in the evolution of Lake Uinta of Johnson (1985). The rich and lean zone from R-1 and above were originally defined by Cashion and Donnell (1972). The R-0 and L-0 zones were added later (for example, see Johnson and others, 1988). U-53 is in the northeast corner of the Uinta Basin, C-158 is in the central part of the Piceance Basin, and core holes CO-172 and CO-195 are in the southeastern and central parts of the Piceance Basin, respectively.

these oil shale beds and zones appear to correlate with time-stratigraphic units that reflect changing rates of organic matter production and preservation that occurred simultaneously throughout Lake Uinta.

A major north-flowing drainage entered the Uinta Basin from the south near the south end of the cross section presented herein. The intertonguing relationships between marginal lacustrine rocks deposited in Lake Uinta and fluvial rocks deposited by this drainage were mapped in detail by Cashion (1967). The Douglas Creek Member was subdivided by Cashion (1967) into tongues A through F in this area, and many of these tongues are shown on the cross section (sheet 1). The extent of the deltaic facies related to this drainage over the course of several time periods are shown on a series of paleogeographic maps compiled by Johnson (1985). The sandy fluvial and marginal lacustrine facies appear to be confined to the upper part of the Wasatch Formation and Green River Formation suggesting that the influence of this north-flowing river on sedimentation in the basin increased with time.

Variations in Thermal Maturity Using Rock-Eval and Vitrinite Reflectance

Two different methods for measuring variations in thermal maturity were plotted on the cross section: (1) Rock-Eval pyrolysis (for a summary, see Tissot and Welte, 1984), and (2) vitrinite reflectance. In Rock-Eval pyrolysis, the sample is heated at 300 °C for 3–5 minutes (min), at which point bitumen less than C_{33} and other volatile compounds that were originally present in the sample are released and measured (S_1 peak). The sample is then progressively heated to 550–600 °C, distilling heavy bitumen and releasing hydrocarbons generated by the cracking of kerogen (S_2 peak). The ratio of S_1/ S_1+ S_2 is called the transformation ratio (production index). For any given kerogen type, the transformation ratio generally increases with increasing thermal maturity. Anders and Gerrild (1984) found that Type 1 organic matter in the Uinta Basin has a transformation ratio of greater than about 0.1, which indicated that the sample was mature with respect to oil generation. T_{max} represents the temperature at which kerogen in the sample generates the most hydrocarbons, and it has been used as a thermal maturity indicator. However, T_{max} for Type 1 kerogen such as those found in the Green River Formation appears to be relatively insensitive to increasing thermal maturity (Espitalie and others, 1986; Anders and others, 1992). The hydrogen to carbon ratio (H/C) is an important parameter in determining both the hydrocarbon generating potential of kerogen and thermal maturity (Waples, 1981; Hunt, 1996; Baskin, 1997). For Type 1 kerogen found in the Green River Formation in the Uinta Basin, Anders and others (1992, fig. 6) determined that there was a close relationship between H/C ratio and thermal maturity as measured by vitrinite reflectance.

Vitrinite reflectance (R_o) is a measurement of the percentage of light reflected off the vitrinite maceral at ×500 magnification in oil immersion, and is commonly used as a measure of thermal maturity in organic-rich rocks. The vitrinite maceral is formed from woody plant tissue, whereas most kerogen found in the Green River Formation in the Uinta Basin is derived from algal material. Thus, studying variations in vitrinite reflectance is an indirect measurement of thermal maturity of the largely Type 1 kerogen in the Green River Formation of the Uinta Basin. For Type 1 kerogen, the onset of oil generation is thought to correspond to a vitrinite reflectance of about 0.75 percent, with oil generation complete at about R_o of 1.2 to 1.3 percent (Baskin and Peters, 1992; Ruble and others, 2001).

Vitrinite reflectance results were published by Anders and others (1992) for four of the drill holes used on the cross section, and the information is plotted next to these drill holes (sheet 1). In addition, Anders and others (1992) published vitrinite reflectance measurements for surface samples throughout the basin. Two of these fall close to the axis of cross section and are projected onto the section from their approximate positions. Anders and others (1992) published T_{max} values for five samples and H/C ratios for two samples in the Sun Oil Co. 1 Daniel Uresk well along the line of section (well no. 14), and these values are plotted next to that well on the cross section (sheet 1).

The approximate positions of two vitrinite reflectance isoreflectance values are shown on the cross section: (1) R_o 0.50 percent, and (2) R_o 0.75 percent, which is correlated to the onset of oil generation in Type 1 kerogen (sheet 1). The two isoreflectance lines dip markedly to the north, indicating that thermal maturities at any given elevation decrease northward and toward the axis of the basin adjacent to the Uinta Mountains. This was previously documented by Nuccio and others (1992) who suggested that this relationship could be in part explained by uplift of the margins of the basin bringing rocks with higher maturities to shallower levels while the trough of the basin was still subsiding and receiving sediments. The decrease in thermal gradients toward the axis of the Uinta Basin, noted by Chapman and others (1984) and Anders and others (1992), also probably played a role. These low thermal gradients near the basin axis are thought to be the result of cold meteoric water percolating into faults along the basin's north margin and heat being carried away by the thick, highly conductive Precambrian Uinta Mountain quartzite that was brought in contact with basin sediments by faulting (Chapman and others, 1984; Anders and others, 1992). The isoreflectance lines in the cross section are shown to abruptly bend upward over Monument Butte field to accommodate the comparatively high R_o value of 0.55 percent obtained from a surface sample over that field. The suggestion that thermal maturities are atypically elevated over Monument Butte field is based on a single surface sample located 5,000–6,000 ft above the producing interval at that site is tenuous at best.

A detailed vitrinite reflectance and Rock-Eval analysis of the Daniel Uresk well about 2–3 miles downdip from Monument Butte Oil Field (well number 14, sheet 1) was published by Anders and others (1992). Vitrinite reflectance values increase from 0.54 percent at a depth of 5,035 ft, located significantly above the productive Uteland Butte interval to 0.94 percent at 11,075 ft in the lower part of the Wasatch Formation, which is significantly below the productive interval (sheet 1). An R_o of 0.67 percent, or somewhat lower than the onset of hydrocarbon generation at R_o 0.75 percent, was obtained from the Uteland Butte member at a depth of 7,805 ft. T_{max} values vary irregularly from 446 to 451 °C throughout the well (sheet 1), supporting the idea that T_{max} is an unreliable measure of thermal maturity for Type 1 kerogen. Hydrogen to carbon ratios (H/C) decrease with increasing depth from 1.33 at 5,035 ft, in the R-5 oil shale zone (R_o 0.54 percent), to 1.18 in the Uteland Butte member at 7,805 ft (R_o 0.67 percent; sheet 1). Transformation ratios (S_1/ S_1+ S_2) increase with depth from a minimum of 0.07 percent at 5,035 ft to a maximum of 0.43 in the middle of the Uteland Butte member, and then decrease to a low of 0.07 percent below Uteland Butte at a depth of 11,075 ft (sheet 1).

A vitrinite reflectance of 0.67 percent at 7,805 ft of the Uteland Butte member in the Daniel Uresk well indicates that the member is immature for oil generation. The unusually high production index of 0.43 for the Uteland Butte member in that well was attributed by Anders and Gerrild (1984, p. 520) to migrated hydrocarbons. The H/C ratio of 1.18 indicates that the Uteland Butte member ranges from immature to marginally mature. Thus, thermal maturities must increase markedly between the Daniel Uresk well and the updip Monument Butte field for the oil in that field to have been generated in situ suggesting that the oil produced from that field migrated from more thermally mature source rocks elsewhere in the basin.

Fischer Assay Analysis

The Fischer assay method is a standardized laboratory test for determining the oil yield from oil shale, and has been almost universally used to determine oil yields for Green River Formation oil shales (Stanfield and Frost, 1949; American Society for Testing Materials, 1984). It is a much simpler, less rigorous analytical procedure than Rock-Eval. The Fischer assay standard method consists of heating a crushed and sieved (–8 mesh (2.38 millimeter mesh)) 100 gram sample in a small aluminum retort to 500 °C at a rate of 12 °C/min and then held at that temperature for 40 min. The volatile vapors of shale oil, gas, and water pass through a condenser cooled with ice water (about 5 °C) and are collected in a graduated centrifuge tube. The oil and water are then separated by centrifugation and weighed. The quantities reported in the original sample are the weight percentages of shale oil, water, shale residue (containing carbon char), and "gas plus loss" (non-condensable gas yield). The specific gravity of the shale oil is measured and used to calculate the oil yield in GPT.

The Fischer assay method does not determine the total amount of hydrocarbons in an oil shale sample nor does it measure the amount or composition of the gases released during the heating of the sample. These gases—chiefly light hydrocarbons, hydrogen, and carbon dioxide—are reported as the "gas plus loss." In addition, it does not distinguish between hydrocarbons originally present in the sample (S_1 peak of Rock-Eval analysis) and hydrocarbons generated from kerogen during pyrolysis (S_2 peak).

Seven of the drill holes had oil yield analyses in GPT based on the Fischer assay method. During the 1960s and 1970s, the U.S. Bureau of Mines ran Fischer assay analysis on cuttings from a large number of drill holes in the Uinta Basin to evaluate the oil shale resources in the Uinta Basin. These analyses were used in the recent reassessment of oil shale resources in the Uinta Basin by Johnson and others (2010b). The original Fischer assay analysis for all drill holes in the Uinta Basin can also be accessed in that publication. Histograms showing variations in GPT of oil generated by Fischer assay for these seven drill holes are shown in sheet 1. Results indicate that productive intervals in the lower part of the Green River Formation at Monument Butte field contain significant quantities of kerogen and oil, however, only the Mahogany zone averages more than 10 GPT. The Mahogany zone is probably immature for hydrocarbon generation along the axis of section and has not been a target for hydrocarbon exploration.

Pressure Gradients

Pressure gradients, determined from the maximum recorded shut-in pressures during drill-stem tests are listed in the table of drill hole information on sheet 1 and plotted at their proper depth next to the drill holes on the cross section. Pressure gradients are calculated by dividing the maximum shut in pressure at the depth of the base of the drill-stem test. A normal pressure gradient in a reservoir where saline water is the pressurizing fluid is about 0.43 pounds per square inch per foot (psi/ft). Pressure gradients that are as high as 0.83 psi/ft occur in the Altamont-Bluebell field. These high pressure gradients have been documented by many workers in the past (for example, see Lucas and Drexler, 1976). Pressure gradients of as high as 0.51 psi/ft were recorded in the productive interval at the Monument Butte field indicating moderately overpressured conditions.

Discussion

This paper assembles much of the published stratigraphic, lithologic, thermal maturity, and geochemistry information for a single axis of cross section in the Uinta Basin in an attempt to better understand the recent oil production from low permeability dolomite, and tight shale reservoirs in the Uteland Butte and R-0 intervals. The information presented here, however, is from near the Monument Butte field, but not from within the field itself. Based on this information, it appears that thermal maturities are too low within the field to have generated significant quantities of oil, suggesting that the oil produced from the field migrated from more thermally mature source rocks elsewhere in the basin. However, thermal gradients appear to be somewhat higher in Monument Butte field than at the nearest well outside the field with geochemistry downdip from the field, and it is possible that thermal maturities within the field are within the oil window. Geochemical and thermal maturity information from within Monument Butte Oil Field is needed to better understand this developing shale oil play.

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